Abrasion resistance of sustainable green concrete containing waste tire rubber particles

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Abstract

The development of new environmental friendly concretes such as rubberized concrete is being promoted due to the environmental problems created by the waste tire rubber. Every year millions of tires are discarded, thrown away or buried all over the world, representing a very serious threat to the ecology. In this study, we analyse the potential of waste tire rubber particles as a partial substitute for fine aggregates in normal strength and high strength cement concrete and the resistance to abrasion has been measured. Statistical Analysis was carried out to strengthen the results obtained from experiments. The results show that the use of tire rubber particles can improve the abrasion resistance of concrete, and this can ensure its applications in pavements, floors and concrete highways, or in places where there are abrasive forces between surfaces and moving objects.

Keywords: Abrasion; Mechanical properties; Waste management; Concrete

1. Introduction

Disposal of waste tire rubber has become a major environmental issue in all parts of the world. Every year millions of tires are discarded, thrown away or buried all over the world, representing a very serious threat to the ecology. It is estimated that every year almost 1000 million tires end their useful life and more than 50% are discarded without any treatment. Land filling with tires occupies lot of space, and these spaces provide the potential sites for the breeding of rodents [1], [2], [3] and [4].

Stockpiled tires also present many, health, environmental and economic risks through air, water and soil pollution. Tire burning causes serious fire hazards, increases the temperature of the area, and the poisonous smoke is very dangerous for humans, animals and plants. One of the possible solutions for the use of waste tire rubber is to incorporate into cement based materials, to replace some of the natural aggregates [5], [6], [7] and [15].

Many studies were conducted on rubberized concrete in which waste tire rubber was substituted for aggregates or cement. Reduction in compressive strength limits their applicability in structural buildings. Proper studies were not noticed on the abrasion resistance of rubberized concrete. The abrasion resistance of concrete may be defined as its ability to resist being worn away by rubbing. The concrete which is more resistant to abrasion can be applied in pavements, floors and concrete highways, in hydraulic structures such as tunnels and dam spillways, or in other surfaces upon which abrasive forces are applied between surfaces and moving objects during service [5], [6], [7] and [8].

Zhang and Li [16] studied on the abrasion resistance of concrete in which silica fumes and crumb rubber were taken as the additives. It was reported that the addition of crumb rubber reduced the compressive strength but increased the abrasion resistance of the concrete. The addition of silica fume enhanced both compressive strength and abrasion resistance of rubberized concrete. Concrete with silica fumes had a better abrasion resistance than control concrete and the rubberized concrete had better resistance to abrasion when compared to the silica fume concrete. The abrasion resistance of rubberized concrete increased with the increase of rubber content. Sukontasukkul and Chaikaew [17] mentioned that the crumb rubber blocks exhibited less abrasion resistance than the control mix specimens. The concrete blocks containing a mixture of different sizes of crumb rubber performed better than those with single size rubber aggregates.

Gesoglu et al. [18] and [19] explained that the abrasion resistance of pervious concrete increased with increasing amount of rubber from 0% to 20%. Fine crumb rubber (passing 1 mm sieve) exhibited more resistance to abrasion than tire chips and crumb rubber. The depth of wear reduced from 0.91% to 0.17% when the amount of fine crumb rubber was increased from 0% to 20%. Ahmed et al. [20] used statistical analysis approaches to optimize the durability and serviceability of self-compacting concrete containing metakaolin. It was mentioned that testing validation mixtures and comparing the results from the prediction models manifested the usefulness of these models for estimating the long-term properties of SCC mixtures.

To the best of knowledge, the comparison of abrasion resistance for normal strength rubberized concrete (with three water-cement ratios) and high strength rubberized concrete and its modelling is reported for the first time.

2. Materials and methods

Ordinary Portland cement of grade 43, conforming to IS: 8112-1989 was used. River sand confirming to zone II as per IS: 383-1970 used as fine aggregates. Crushed stone were used as coarse aggregates with specific gravity-2.63. Tire rubber was grinded into three sizes (powder form of 30 mesh: −600 µm, 0.8 to 2 mm, 2–4 mm). The Specific gravity of rubber powder was 1.05 and that of the other two sizes were 1.13. The three sizes of crumb rubber were mixed (2–4 mm size in 25%, 0.8 to 2 mm size in 35% and rubber powder in 40%) to bring it to zone II. Concrete was designed (As per IS: 10262-2010) with w/c 0.4, 0.45, 0.5 and high strength concrete with w/c 0.3. Casting and testing of concrete were performed according to Refs. [9], [10], [11], [12], [13] and [14]. The ratio of cement, fine aggregates and coarse aggregates by weight is given in Table 1. Waste tire rubber (crumb rubber) was partially substituted for fine aggregates from 0% to 20% in multiples of 2.5%.

Table 1. Mixture proportions of fresh concrete

Water-cement ratio	Cement kg/m^3	Silica Fumes kg/m^3	Water kg/m^3	Coarse Aggregates 10 mm kg/m^3	Coarse Aggregates 20 mm kg/m^3	Fine Aggregates kg/m^3	Admixture %
0.40	388.0	0	155.0	465.0	737.2	698.4	0.65
0.45	388.0	0	174.6	465.0	737.2	698.4	0.30
0.50	388.0	0	194.0	465.0	737.2	698.4	0
0.3	450.0	27.000	140.0	355.0	848.0	666.0	2

The abrasion test (resistance to wear) was performed according to IS: 1237-1980 on 28 days cured concrete cubes (which are oven dried at 110 ± 5 °C for 24 h) of 100 mm size. A suitable abrasive powder was used, and a load of 600 N was applied on the specimen as the surface area exposed to wear was 100 cm2. As per the code, in general purpose tiles, the average maximum wear shall not exceed 3.5 mm and wear on any individual specimen shall not exceed 4 mm. For heavy duty floors, it is 2 mm and 2.5 mm, respectively.

3. Analytical results

For comparing the results of the model and measured values, JMP software was used and numerical analysis was carried further to validate the results obtained. The software uses least square method to check the predicted models. In this type of analysis every possible means of combinations are tried i.e. between parameters (A, B, C, AB, AC, CB, ABC) and polynomial to degree two i.e. (A, B, C, A2, B2, C2) and combinations of both.

$$\text{Model depth of abrasion, (mm)} = M - 0.0152R$$

M is the constant depending on the mixture with M1 = 1.41; M2 = 1.52; M3 = 1.46; M4 = 1.29 (mm) and R in model's equation is the rubber replacement ratio (%). This model has a R2 of 0.80 and RMSE of 0.07. Analysis of Variance Prob > F is less than 0.0001. In statistical analysis, R2 is a number that indicates how well data fit a statistical model. The closer to 1, the better is the model. RMSE is the root-mean-square error, it represents the sample standard deviation of the differences between predicted values and observed values in ANOVA with a very low F we can conclude that the null hypothesis is not rejected. A t-test is any statistical hypothesis test in which the test statistic follows a Student's t distribution if the null hypothesis is supported. This should be low for every parameter observed and added to the model. While predicting the model, all the mixture specific constants like w/c and other constants were removed. All these were grouped under one constant M1, M2, M3, M4 and these constants vary for every mixture. Fig. 1 shows the fitness of the model with the corresponding measured data.

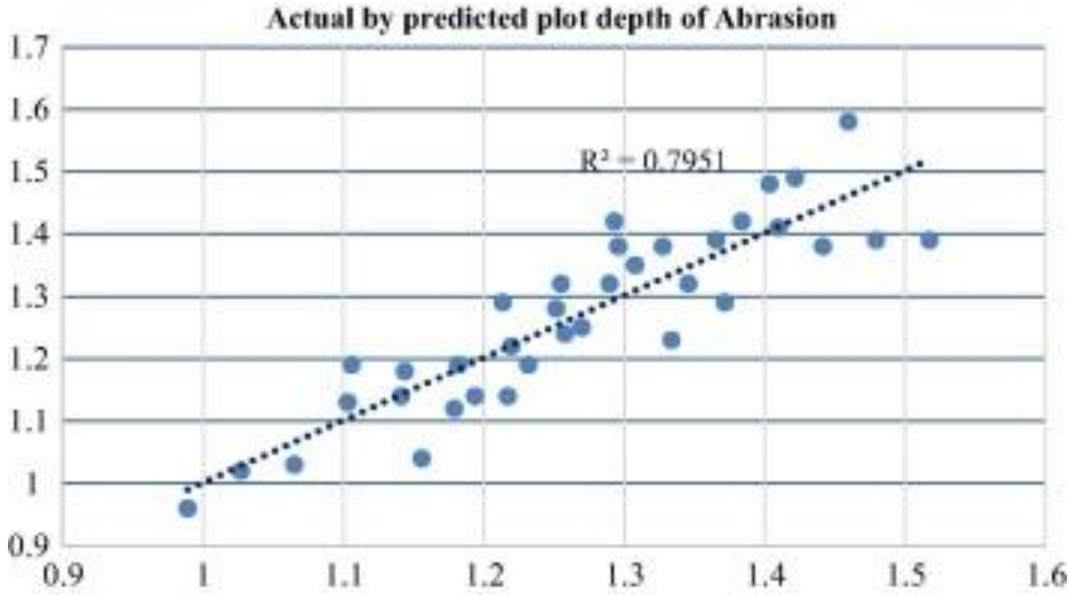

Fig. 1. Depth of abrasion actual vs predicted plot

Fig. 2 shows that the amount of rubber has a negative linear effect of the depth i.e. it have a linear positive effect on the resistance against abrasion.

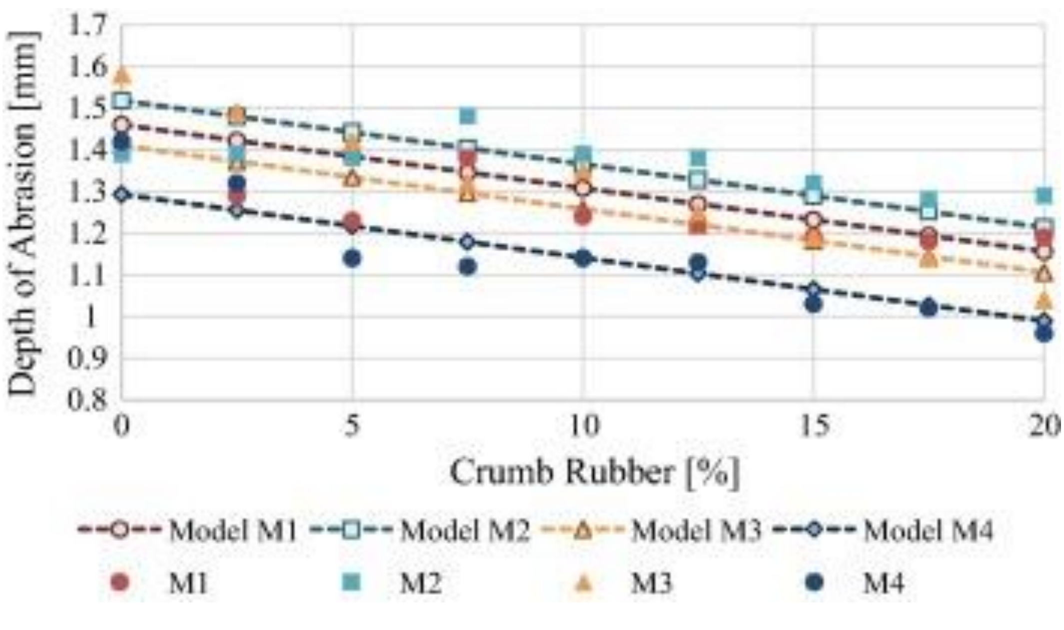

Fig. 2. Depth of measured abrasion value vs model value

4. Results and discussion

Deterioration of concrete can take place due to abrasion caused by various exposures (rubbing, skidding or sliding of the object) on the surface of concrete. Fig. 3 shows the variations in the depth of surface wear (abrasion) with respect to the percentage of crumb rubber [6]. It was observed that the rubberized concrete exhibited better resistance to abrasion than the control mix. When the water-cement ratio was 0.4, the depth of abrasion was 1.41 mm for the control mix and the abrasion depth for all the mixes up to 20% crumb rubber substitution was less than 1.41 mm. When the water-cement ratio was 0.45, the mix with a rubber content of 7.5% showed less abrasion resistance than that of the control mix, while all the other mixes showed better resistance to abrasion than the control mix. The abrasion test result of water-cement ratio 0.5 was similar to that of 0.4, where the rubberized concrete showed better resistance to abrasion than the control mix. At water-cement ratio 0.3, the maximum depth of abrasion (1.42 mm) was observed for the control mix with 0% crumb rubber and the minimum value (0.96 mm) was obtained in the concrete with 20% crumb rubber. As all the values were less than 2 mm, it could be implemented in both general purpose tiles and heavy duty floor tiles.

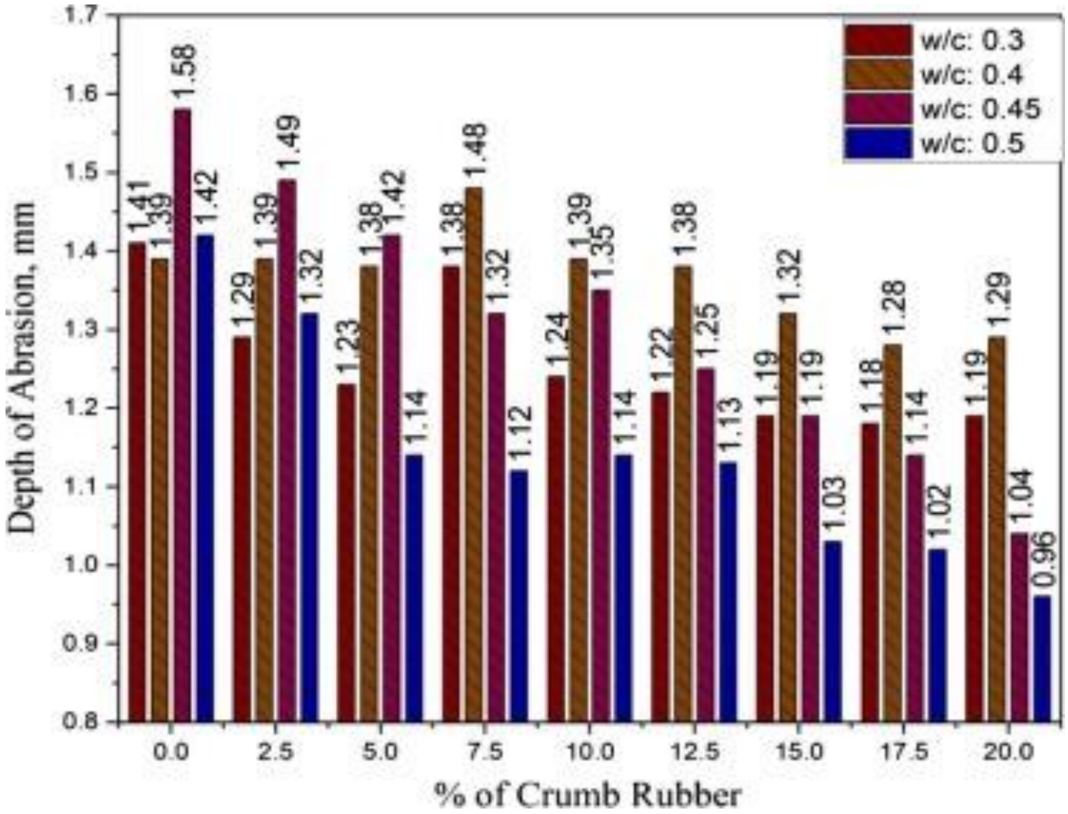

Fig. 3. Abrasion resistance of specimen

The water-cement ratio does not prove to have much influence on the abrasion resistance of rubberized concrete specimens. The specimens exhibited more resistance to abrasion when the water-cement ratio was higher. All the concrete specimens with crumb rubber showed better resistance to abrasion when compared to the control mix.

The results obtained in this study can be compared with the observations made by Sukontasukkul and Chaikaew [17], and Gesoglu et al. [18] and [19] who observed that the abrasion resistance of pervious concrete increased with increasing amount of rubber from 0% to 20%. The major finding of this research was the reason behind the high abrasion resistance of rubberized concrete From the Fig. 4, it is understood that during the abrasion test, the crumb rubber particles present in the rubberized concrete projected beyond the smooth surface of the concrete and restricted the grinding/rubbing of the concrete surface by acting like a brush [6]. This minimized the action of abrasive powder on the surface of concrete and hence the rubberized concrete became more resistant to abrasion when compared to the control mix.

Fig. 4. Surface of the control mix (0% rubber) and rubberized concrete after Abrasion test [6]

Observing the surfaces of crumb rubber and river sand from Fig. 5, typically smooth and solid surfaces could be seen on river sand, while varied and irregular appearance on the crumb rubber. Some parts are relatively smooth, with occasional spherical indentations, most likely as a result of the comminution process leaving behind such typical clam shaped crevices. In theory, this would allow securing the particles in the matrix by interlocking with cement paste, however, the bond between rubber particles and cement paste is not as good as with traditional rigid aggregates, which may also offer some infiltration of cement paste through their surface and even chemical reactions with it, which are unlikely to occur with rubber crumbs. From the SEM images of concrete specimens, there are cracks and voids to note around rubber particles at the interface of the crumb rubber and cement paste, which reflects the weak bond between the crumb rubber and cement mortar leading to reduced compressive strength of concrete.

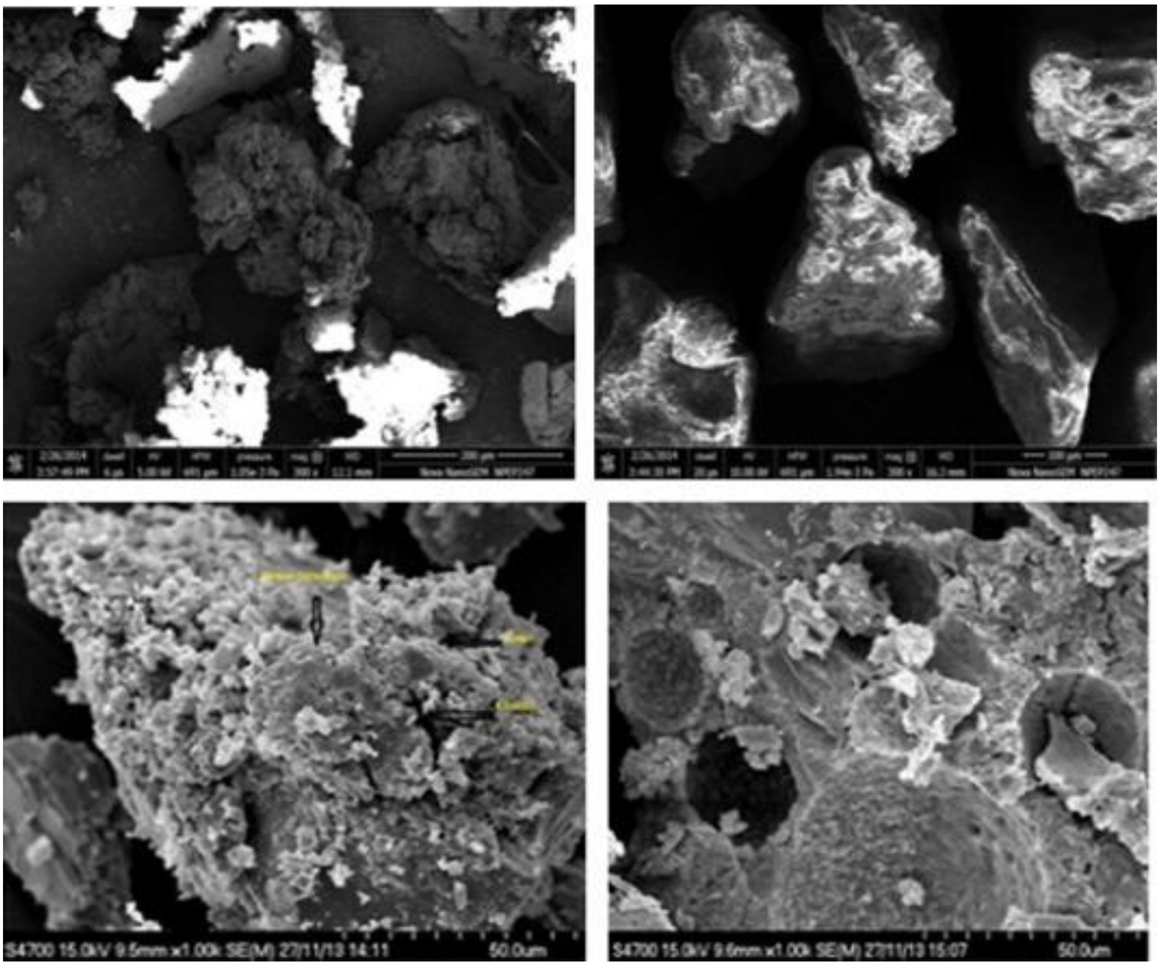

Fig. 5. SEM images of crumb rubber (top left) and river sand (top right) passing through 300 µ sieve, SEM images of control mix (0% rubber-bottom left) and concrete with 20% crumb rubber (bottom right) [21], [22], [23], [24] and [25]

5. Conclusions

The weak bonding between the cement paste and the crumb rubber (as observed in the SEM images) has not affected the abrasion resistance on the rubberized concrete, as it affected the compressive strength. When compared to the control concrete without rubber, the Rubberized concrete is more resistant to abrasion. The statistical analysis reveals that the amount of rubber has a negative linear effect of the depth. i.e. it have a linear positive effect on the resistance against abrasion. So it can be applied in pavements, floors and concrete highways, in hydraulic structures such as tunnels and dam spillways, or in other surfaces upon which the abrasive forces are applied between surfaces and moving objects during service.

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